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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: MICROSTRIP PATCH ANTENNA WITH FRACTAL STRUCTURE

5   **MICROSTRIP PATCH ANTENNA WITH FRACTAL STRUCTURE**

RELATION TO PREVIOUSLY FILED PATENT APPLICATION

This application claims priority from applicant's U.S.

10   patent application 08/965,914 filed 7 November 1997 enti-

tled "MICROSTRIP PATCH ANTENNA WITH STRUCTURE".

Applicant also refers to and incorporates herein by ref-

is directly proportional to the antenna perimeter. For
example, if one doubles the length of an Euclidean square
(or "quad") antenna, the enclosed area of the antenna
quadruples. Classical antenna design has dealt with
5   planes, circles, triangles, squares, ellipses, rectan-
gles, hemispheres, paraboloids, and the like, (as well
as lines).

With respect to antennas, prior art design philosophy has
10   been to pick a Euclidean geometric construction, e.g., a
quad, and to explore its radiation characteristics, espe-
cially with emphasis on frequency resonance and power
patterns. The unfortunate result is that antenna design
has far too long concentrated on the ease of antenna
15   construction, rather than on the underlying electro-
magnetics.

Many prior art antennas are based upon closed-loop or
island shapes. Experience has long demonstrated that
20   small sized antennas, including loops, do not work well,
one reason being that radiation resistance ("R") decreas-
es sharply when the antenna size is shortened. A small
sized loop, or even a short dipole, will exhibit a radia-
tion pattern of $1/2\lambda$ and $1/4\lambda$, respectively, if the radi-
25   ation resistance R is not swamped by substantially larger
ohmic ("O") losses. Ohmic losses can be minimized using
impedance matching networks, which can be expensive and
difficult to use. But although even impedance matched
small loop antennas can exhibit 50% to 85% efficiencies,
30   their bandwidth is inherently narrow, with very high Q,
e.g., Q>50. As used herein, Q is defined as (transmitted
or received frequency)/(3 dB bandwidth).

Applicant's above-referenced co-pending patent applica-
35   tions depict examples of fractal geometry, which geometry
may be grouped into random fractals, which are also

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termed chaotic or Brownian fractals and include a random
noise components, or deterministic fractals.

In deterministic fractal geometry, a self-similar struc-
ture results from the repetition of a design or motif (or
"generator"), on a series of different size scales. One
well known treatise in this field is Fractals, Endlessly
Repeated Geometrical Figures, by Hans Lauwerier, Prince-
ton University Press (1991), which treatise applicant
refers to and incorporates herein by reference. Lau-
werier notes that in its replication, the motif may be
rotated, translated, scaled in dimension, or a combina-
tion of any of these characteristics. Thus, as used
herein, second order of iteration or N=2 means the funda-
mental motif has been replicated, after rotation, trans-
lation, scaling (or a combination of each) into the first
order iteration pattern. A higher order, e.g., N=3,
iteration means a third fractal pattern has been generat-
ed by including yet another rotation, translation, and/or
scaling of the first order motif.

Unintentionally, first order fractals have been used to
distort the shape of dipole and vertical antennas to
increase gain, the shapes being defined as a Brownian-
type of chaotic fractals. See F. Landstorfer and R.
Sacher, Optimisation of Wire Antennas, J. Wiley, New York
(1985).

So-called microstrip patch antennas have traditionally
been fabricated as two spaced-apart metal surfaces sepa-
rated by a small width dielectric. The sides are dimen-
sioned typically one-quarter wavelength or one-half wave-
length at the frequency of interest. One surface is
typically a simple euclidean structure such as a circle,
a square, while the other side is a ground plane.

Attempting to reduce the physical size of such an antenna
for a given frequency typically results in a poor feed-
point match (e.g., to coaxial or other feed cable), poor
radiation bandwidth, among other difficulties.

5

Prior art antenna design does not attempt to exploit
multiple scale self-similarity of real fractals. This is
hardly surprising in view of the accepted conventional
wisdom that because such antennas would be anti-resona-
10   tors, and/or if suitably shrunken would exhibit so small
a radiation resistance R, that the substantially higher
ohmic losses O would result in too low an antenna effi-
ciency for any practical use. Further, it is probably
not possible to mathematically predict such an antenna
15   design, and high order iteration fractal antennas would
be increasingly difficult to fabricate and erect, in
practice.

Thus, the use of fractals, especially higher order frac-
20   tals, in fabricating microstrip patch antennas has not
been investigated in the prior art.

Applicant's above-noted FRACTAL ANTENNA AND FRACTAL RESO-
NATORS patent application provided a design methodology
25   to produce smaller-scale antennas that exhibit at least
as much gain, directivity, and efficiency as larger Eu-
clidean counterparts. Such design approach should ex-
ploit the multiple scale self-similarity of real
fractals, including N≥2 iteration order fractals. Fur-
30   ther, said application disclosed a non-Euclidean resona-
tor whose presence in a resonating configuration can
create frequencies of resonance beyond those normally
presented in series and/or parallel LC configurations.
Applicant's above-noted TUNING FRACTAL ANTENNAS AND FRAC-
35   TAL RESONATORS patent application provided devices and
methods for tuning and/or adjusting such antennas and
resonators. Said application furth r disclosed the use

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of non-Euclidean resonators whose presence in a resonat-
ing configuration could create frequencies of resonance
beyond those normally presented in series and/or parallel
LC configurations.

5

However, such antenna design approaches and tuning ap-
proaches should also be useable with microstrip patch
antennas and elements for such antennas. Thus, there is
a need for a method by which microstrip patch antennas
10   could be made smaller without sacrificing antenna band-
width, while preserving good feedpoint impedance match-
ing, and while maintaining acceptable gain and frequency
characteristics.

15   The present invention provides such microstrip patch
antennas, and elements for such antennas.

SUMMARY OF THE INVENTION

The present invention provides a microstrip patch antenna
20   comprising spaced-apart first and second conductive sur-
faces separated by a dielectric material. The dielectric
material thickness preferably is substantially less than
one wavelength for the frequency of interest.

25   At least one of the surfaces is fabricated to define a
fractal pattern of first or higher iteration order.
Overall dimensions of the surfaces may be reduced below
the one-quarter to one-half wavelength commonly found in
the prior art.

30

Radio frequency feedline coupling to the microstrip patch
antenna may be made at a location on the antenna pattern
structure, or through a conductive feedtab strip that may
be fabricated along with the conductive pattern on one or

mance at about 900 MHz.) while preserving good, prefera-
bly 50Ω, feedpoint impedance. Further bandwidth can
actually be increased, and resonant frequency lowered.

5   Other features and advantages of the invention will ap-
pear from the following description in which the prefer-
red embodiments have been set forth in detail, in con-
junction with the accompanying drawings.

10   BRIEF DESCRIPTION OF THE DRAWINGS
FIGURE 1 is a sideview of a microstrip patch antenna with
at least one fractal element, according to the present
invention;

15   FIGURE 2 is a top plan view of an exemplary fractal
element (a Sierpinski square gasket, including an option-
al feedtab, according to the present invention;

FIGURE 3 is a top plan view of an exemplary alternative
20   fractal element (a diffusion limited aggregate), includ-
ing an optional feed pad, according to the present inven-
tion.

         DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS
25   In overview, the present invention provides a microstrip
patch antenna with at least one element whose shape, at
least is part, is substantially a fractal of iteration
order N≥1. The resultant antenna is smaller than its
Euclidean counterpart, provides close to 50Ω termination
30   impedance, exhibits acceptable gain, increased bandwidth,
and decreased resonant frequency than its Euclidean coun-
terpart.

In contrast to Euclidean geometric antenna design, a
35   fractal antenna ground counterpoise according to the
present invention has a perimeter that is not directly
proportional to area. For a given perimeter dimension,

the enclosed area of a multi-iteration fractal area will
always be at least as small as any Euclidean area.

Using fractal geometry, the ground element has a self-
5   similar structure resulting from the repetition of a
design or motif (or "generator"), which motif is repli-
cated using rotation, translation, and/or scaling (or any
combination thereof). The fractal portion of the element
has x-axis, y-axis coordinates for a next iteration N+1
10   defined by $x_{N+1} = f(x_N, yb_N)$ and $y_{N+1} = g(x_N, y_N)$, where
x_N, y_N are coordinates of a preceding iteration, and
where $f(x,y)$ and $g(x,y)$ are functions defining the frac-
tal motif and behavior.

15   For example, fractals of the Julia set may be represented
by the form:

$$x_{N+1} = x_N^2 - y_N^2 + a$$
$$y_{N+1} = 2x_N \cdot y_N = b$$

In complex notation, the above may be represented as:

$$z_{N+1} = z_N^2 + c$$

Although it is apparent that fractals can comprise a wide
20   variety of forms for functions $f(x,y)$ and $g(x,y)$, it is
the iterative nature and the direct relation between
structure or morphology on different size scales that
uniquely distinguish $f(x,y)$ and $g(x,y)$ from non-fractal
forms. Many references including the Lauwerier treatise
25   set forth equations appropriate for $f(x,y)$ and $g(x,y)$.

Iteration (N) is defined as the application of a fractal
motif over one size scale. Thus, the repetition of a
single size scale of a motif is not a fractal as that
term is used herein. Multi-fractals may of course be
30   term is used herein. Multi-fractals may of course be

Referring now to Figure 1, a microstrip patch antenna 10
according to the present invention is shown coupled by
coaxial or other cable (or equivalent) 20 to a source of
radio frequency 30. Antenna 10 comprises a substrate 40
5   whose top-to-bottom thickness is preferably substantially
less than one wavelength at the frequency of interest,
e.g., the radio frequency or band of radio frequencies
coupled by cable 20 to antenna 10. Preferably the effec-
tive dimension of substrate is one-eighth wavelength at
10   such frequency.

On its first surface, substrate 40 is initially covered
by a conductive layer of material 50 that is etched away
or otherwise removed in areas other than the desired
15   fractal pattern (60) design, to expose the substrate.
The remaining conductive trace portion defines a fractal
element, according to the present invention.

Similarly on its second surface, substrate 40 is initial-
20   ly covered by a conductive layer of material 70 that is
selectively removed so as to leave a desired pattern (80)
that may also be a fractal pattern, according to the
present invention. Alternatively, conductive material
defining the desired patterns 60, 80 could be deposited
25   upon substrate 40, rather than beginning fabrication with
a substrate clad or otherwise having conductive surfaces,
portions of which are removed.

Preferably feedtabs 90 and 100 are coupled, respectively,
30   to edge regions of the first and second surfaces of sub-
strate 40 to facilitate electrical radio frequency cou-
pling between cable 20 and patterns 60 and/or 80. These
feedtabs preferably are etched using the same conductive
material originally found on the upper or lower surfaces
35   of substrate 40, or may otherwise be formed using tech-
niques known to those skilled in the relevant art. If
patterns 60 and 80 are deposited rather than etched, then

feedtabs 90, 100 may be deposited at the same fabrication step.

Substrate 40 is a non-conductive material, and by way of
5   example may be a silicon wafer, a rigid or a flexible
plastic-like material, perhaps Mylar^{TM} material, or the
non-conductive portion of a printed circuit board, paper,
epoxy, among other materials. The original conductive
material on the first and/or second surfaces may be de-
10   posited doped polysilicon for a semiconductor substrate
40, or copper (or other conductor) for a printed circuit
board substrate.

Figure 2 is a plan view of one surface of antenna 10 (it
15   matters not which), and depicts a first iteration fractal
conductive pattern, although a fractal pattern with high-
er than first iteration could instead be used. The pat-
tern shown in Figure 2 is often referred to as a
Siepinski (square) gasket pattern. A margin is shown in
20   Figure 2 between the outer perimeter of the pattern and
the edge of the substrate; however no such margin is
required. Although Figure 2 shows inclusion of feedtab
90 or 100, radio frequency feed may be made elsewhere on
the surface, for example at any point 110.
25
If the fractal pattern of Figure 2 represents one surface
of antenna 10, the opposite surface need not define a
fractal pattern, but may in fact do so. For example, one
surface may define a fractal pattern and the opposite
30   surface may be entirely conductive, or may define on the
substrate a conductive circle, etc. If the pattern on
the opposite surface is also a fractal, there is no re-
quirement that it be the same iteration fractal as is
defined on the first surface, or that it be the same
35   fractal type. While common fractal families include
Koch, Minkowski, Julia, diffusion limited aggregates,
fractal trees, Mandelbrot, microstrip patch antennas with

fractal element(s) according to the present invention may
be implemented with other fractals as well.

Figure 3 depicts a pattern 60 or 80 in which a different
5   fractal pattern is defined, a so-called diffusion limited
aggregate pattern. It is understood, however, that ac-
cording to the present invention, a great variety of
fractal patterns of first or higher iteration may be
defined on the first and/or second surface of antenna 10.
10   In Figure 3, while a feedtab 90 or 100 is shown, it is
again understood that radio frequency feed may be made
essentially anywhere on the fractal pattern, e.g., at a
point 110.

15   In one embodiment, applicant fabricated an antenna 10
having sides dimensioned to about one-eighth wavelength
for a frequency of about 900 MHz. Those skilled in the
art will readily appreciate that a microstrip patch an-
tenna dimensioned to one-eighth wavelength is substan-
20   tially smaller than prior art non-fractal microstrip
patch antennas, in which dimensions are one-quarter or
one-half wavelength in size. At 900 MHz, bandwidth was
about 5% to about 8% of nominal frequency. Gain and
matching impedance were acceptable, and indeed substan-
25   tially 50Ω impedance is realized without the need for
impedance transforming devices.

Modifications and variations may be made to the dis-
closed embodiments without departing from the subject and
30   spirit of the invention as defined by the following
claims. It will be appreciated, for example, that the
present invention may be implemented and adjusted and
used in ways described in any of applicant's referenced
co-pending applications.
35

WHAT IS CLAIMED IS:

    1.   A microstrip patch antenna including:

    a substrate having spaced-apart first and second surfaces, said substrate having a thickness substantially smaller than a wavelength at a frequency to be coupled to said antenna;

    a conductive pattern defining a fractal of iteration order N disposed on the first surface; and

    a conductive pattern disposed on the second surface.

    2.   The antenna of claim 1, wherein said pattern on said second surface defines a fractal.

    3.   The antenna of claim 1, wherein said fractal on said first surface is defined as a superposition over at least N=1 iterations of a fractal generator motif, an iteration being placement of said fractal generator motif upon a base figure through at least one positioning selected from the group consisting of (i) rotation, (ii) stretching, and (iii) translation.

    4.   The antenna of claim 3, wherein said fractal generator motif has x-axis, y-axis coordinates for a next iteration N+1 defined by $x_{N+1} = f(x_N, y_N)$ and $y_{N+1} = g(x_N, y_N)$, where x_N, y_N are coordinates for iteration N, and where f(x,y) and g(x,y) are functions defining said fractal generator motif.

    5.   The antenna of claim 3, wherein said fractal generator motif is selected from a family consisting of (i) Koch, (ii) Minkowski, (iii) Cantor, (iv) torn square, (v) Mandelbrot, (vi) Caley tree, (vii) monkey's swing, (viii) Sierpinski gasket, and (ix) Julia.

    6.   The antenna of claim 3, wherein said antenna has a perimeter compression parameter (PC) defined by:

$$PC = \frac{\text{\textit{full-sized antenna element length}}}{\text{\textit{fractal-reduced antenna element length}}}$$

where:

$$PC = A\cdot\log[N(D + C)]$$

in which A and C are constant coefficients for a given
said fractal generator motif, N is an iteration number,
and D is a fractal dimension given by $\log(L)/\log(r)$,
5   where L and r are one-dimensional antenna element lengths
before and after fractalization, respectively.

        7.   The antenna of claim 1, in which said antenna
is fabricated in a manner selected from the group con-
10   sisting of (i) forming upon an insulator substrate a
conductive layer defining said fractal, (ii) forming upon
a flexible insulator substrate a conductive layer defin-
ing said fractal; (iii) forming upon a semiconductor
substrate a layer of conductive material to define said
15   fractal, and (iv) removing from a substrate having a
surface covered with conductive material a portion of
said conductive material to form said fractal.

        8.   The antenna of claim 1, wherein said substrate
20   is sized to less than one-quarter wavelength at a fre-
quency of radio frequency signals to be coupled to said
antenna.

        9.   The antenna of claim 1, wherein said substrate
25   is sized to approximately one-eighth wavelength at a
frequency of radio frequency signals to be coupled to
said antenna.

        10.   The antenna of claim 9, wherein said frequency
30   is approximately 900 MHz.

        11.   A method of fabricating a microstrip patch
antenna, the method including the following steps:

(a) providing a substrate having spaced-apart first and second surfaces and having a substrate thickness substantially smaller than a wavelength at a frequency to be coupled to said antenna;

5   (b) disposing on the first surface of said substrate a conductive pattern defining a fractal of iteration order N formed; and

(c) disposing on the second surface of said substrate a conductive pattern.

10

12. The method of claim 11, wherein at step (c) said conductive pattern is formed so as to define a fractal.

15   13. The method of claim 11, wherein at step (b), said fractal on said first surface is defined as a superposition over at least N=1 iterations of a fractal generator motif, an iteration being placement of said fractal generator motif upon a base figure through at least one
20   positioning selected from the group consisting of (i) rotation, (ii) stretching, and (iii) translation.

14. The method of claim 13, wherein said fractal generator motif has x-axis, y-axis coordinates for a next
25   iteration N+1 defined by $x_{N+1} = f(x_N, y_N)$ and $y_{N+1} = g(x_N, y_N)$, where x_N, y_N are coordinates for iteration N, and where $f(x,y)$ and $g(x,y)$ are functions defining said fractal generator motif.

30   15. The method of claim 13, wherein said fractal generator motif is selected from a family consisting of (i) Koch, (ii) Minkowski, (iii) Cantor, (iv) torn square, (v) Mandelbrot, (vi) Caley tree, (vii) monkey's swing, (viii) Sierpinski gasket, and (ix) Julia.

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16. The method of claim 13, wherein said antenna has a perimet r compression parameter (PC) defined by:

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$$PC = \frac{full\text{-}sized\ antenna\ element\ length}{fractal\text{-}reduced\ antenna\ element\ length}$$

where:

$$PC = A \cdot \log[N(D + C)]$$

in which A and C are constant coefficients for a given said fractal generator motif, N is an iteration number, and D is a fractal dimension given by $\log(L)/\log(r)$,

5   where L and r are one-dimensional antenna element lengths before and after fractalization, respectively.

17.   The method of claim 11, in which said antenna is fabricated in a manner selected from the group con-

10   sisting of (i) forming upon an insulator substrate a conductive layer defining said fractal, (ii) forming upon a flexible insulator substrate a conductive layer defining said fractal; (iii) forming upon a semiconductor substrate a layer of conductive material to define said

15   fractal, and (iv) providing a substrate having a surface covered with conductive material, and removing a portion of said conductive material to form said fractal.

18.   The method of claim 11, wherein said substrate

20   is sized to less than one-quarter wavelength at a frequency of radio frequency signals to be coupled to said antenna.

19.   The method of claim 11, wherein at step (a)

25   said substrate is sized to approximately one-eighth wavelength at a frequency of radio frequency signals to be coupled to said antenna.

20.   The method of claim 19, wherein said frequency
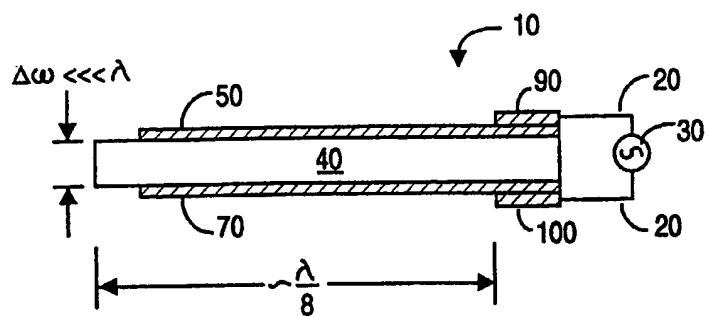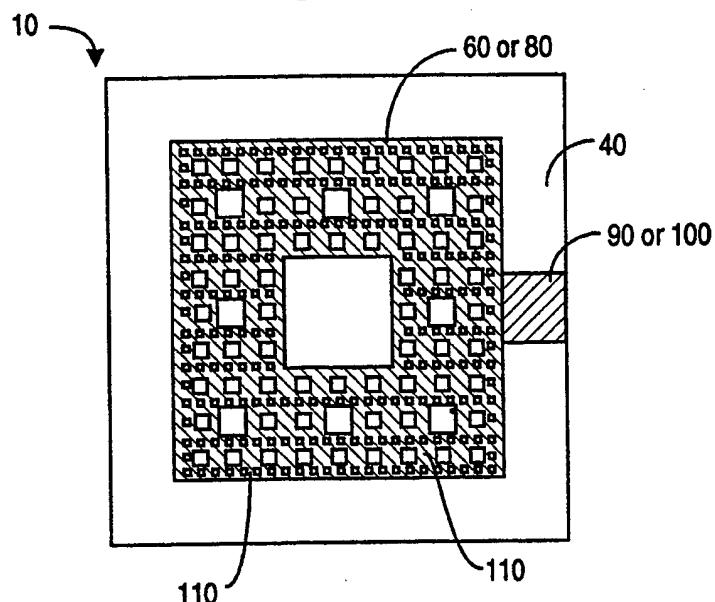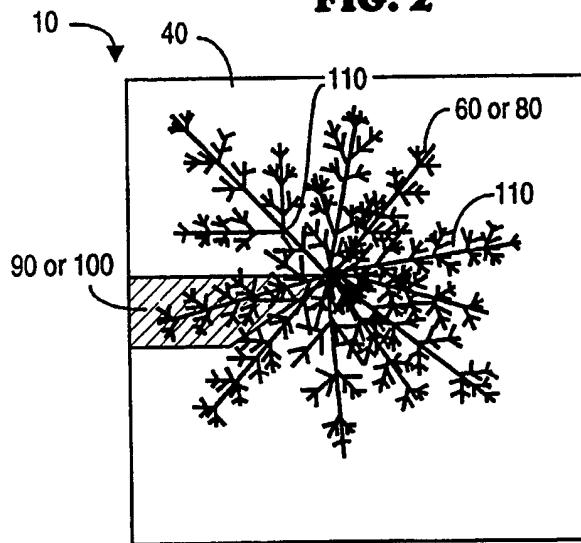
30   is approximately 900 MHz.

FIG. 1

FIG. 2

FIG. 3

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO1Q 1/38

US CL : 343/700ms, 795, 806

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 343/700ms, 795, 806, 792.5, 850

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,006,858 A (SHIROSAKA) 09 April 1991 (09/04/91), see figures 3 and 4.	1,3,4,7,11,13,14, and 17
X	US 5,453,752 A (WANG et al) 26 September 1995 (26/09/95), see figures 2A-2B and 4A-5B.	1,3,4,7-11,13,14, and 17-20

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"E"	earlier document published on or after the international filing date
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"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed

"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance. the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
11 JANUARY 1999	**03 FEB 1999**

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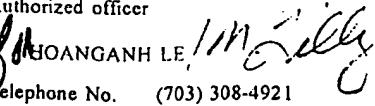
Form PCT/ISA/210 (second sheet)(July 1992)*